Effect of endophyte type on carcass traits, meat quality, and fatty acid composition of beef cattle grazing tall fescue

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ABSTRACT: Fourteen Hereford steers were used to compare carcass traits, meat quality, and fatty acid composition of beef from cattle grazing tall fescue infected with either wild-type (E+; n = 6) or novel, nil ergot alkaloid (AR542; n = 8) endophyte for 209 d. Average daily gain, live weight, and HCW were greater ($P < 0.05$) for AR542 cattle than for E+. No differences in LM color or pH were observed between AR542 and E+. Steaks from E+ cattle tended ($P = 0.10$) to have higher L* and b* than those from AR542 cattle at 0 d of display. Ground beef from E+ cattle also had higher ($P < 0.05$) L* than AR542 cattle, with no differences in a* or b* at 0 d of display. Color changes during display did not differ for both steaks and ground beef from E+ and AR542. Lipid oxidation levels increased ($P < 0.05$) during simulated retail display, but they did not differ between endophyte treatments. Adipose tissues from E+ cattle had a higher ($P < 0.05$) percentage of SFA, and a lower ($P < 0.05$) percentage of MUFA than adipose from AR542 cattle. Ground beef and i.m. fat had higher ($P < 0.05$) concentrations of SFA, MUFA, and *cis*-9, *trans*-11 isomer of conjugated linoleic acid, and lower ($P < 0.05$) concentrations of PUFA and PUFA:SFA ratio than s.c. fat. The n-6:n-3 fatty acid ratio did not differ among fat depots. Ergot-alkaloids were detected in s.c. adipose tissues, and alkaloid concentration was greater ($P < 0.05$) for E+ than AR542. Warner-Bratzler shear force values did not differ between endophyte types, but it decreased ($P < 0.01$) across the postmortem aging period. Conversely, sensory panel evaluation detected greater ($P < 0.01$) chewiness and lower ($P < 0.05$) juiciness for AR542 than for E+ steaks aged for 14 d. Although grazing cattle on tall fescue pastures infected with nil ergot alkaloid endophyte improved cattle performance, these results suggest that endophyte type has minor effects on carcass traits and meat quality of pasture-fed beef. Moreover, finishing cattle on tall fescue pastures showed the potential to enhance the fatty acid profile of beef from a human health perspective. Alkaloid concentration was greater ($P < 0.05$) in s.c. fat from E+ than AR542 (2.81 vs. 0.92 ppb; fresh-tissue basis). This is the first published report demonstrating the presence of alkaloids in beef tissues.

Key Words: Beef Quality, Ergot Alkaloids, Tall Fescue

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Introduction

Tall fescue (*Festuca arundinacea*), a major component of pasture systems in the United States (over 14 million ha), is frequently infected with the endophyte fungus *Neotyphodium coenophialum*. The fungal endophyte shares a symbiotic relationship with tall fescue, protecting the host plant against disease, insects, and drought. At the same time, it has been identified as the causative agent of fescue toxicosis. Some of the symptoms associated with toxicosis include increased respiration rates, rectal temperatures, salivation, nervousness, and rough hair coats, and decreased weight gains and overall performance in beef steers (Hoveland et al., 1983; Stuedemann and Hoveland, 1988). Endophyte-infected tall fescue contains various alkaloids that are candidate toxins presumed to cause the toxicosis syndrome. Stuedemann et al. (1998) and Hill et al. (2001) proposed that the polar ergot alkaloids (lysergamides, lysergic acid, and lysergol) are the toxic entities causing fescue toxicosis.

Management and grazing recommendations have been suggested for alleviating tall fescue toxicosis in beef cattle. More recently, endophytes that produce nil ergot alkaloids have been incorporated into tall fescue cultivars (Bouton et al., 2002) and are commercially available in the United States (Max-Q, Pennington Seed, Madison, GA). Current research has

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shown that tall fescue pastures infected with nil ergot alkaloid endophyte are a promising alternative for combating toxicosis and greatly improve beef productivity (Bouton et al., 2002; Parish et al., 2003; S. K. Duckett, unpublished data). However, no data are available on how endophyte type alters carcass characteristics and beef quality in cattle finished on tall fescue pastures or whether endophytes are deposited in beef tissues. Therefore, the objectives of this study were to determine the effect of endophyte type (novel, nil ergot alkaloid vs. wild-type) in beef cattle grazing tall fescue on carcass traits, meat quality, and fatty acid composition, as well as to detect concentrations of ergot alkaloids, if possible, in s.c. fat.

Materials and Methods

Fourteen Hereford steers (273 ± 35 kg) grazed replicated 0.8 ha/paddock tall fescue pastures infected with either wild-type (**E+**; two pasture replicates; three steers per pasture) or novel, nil ergot alkaloid (**AR542**; four pasture replicates; two steers per pasture) endophyte for 74 d from October to December 2000, and for 102 d from March to July 2001 at the Central Georgia Experiment Station, Eatonton. Put-and-take grazing management was used throughout the grazing season to maintain similar forage availability among treatments. All steers used in this study grazed their respective paddocks for the entire 176-d grazing period. Steers were provided with water, minerals, and shade in each paddock. During the winter months (December to March), steers were maintained on a common pasture and supplemented with bermudagrass hay. These cattle were part of a larger grazing experiment conducted over a 3-yr period (1999 to 2001), and additional grazing information has been reported by Parish et al. (2003). Animal handling procedures for this study were approved by the University of Georgia Animal Care and Use Committee.

At the end of the grazing period, steers were slaughtered at a commercial meat plant, and carcass data collected included adjusted fat thickness, LM area, marbling score, percentage of KPH fat, skeletal maturity, and USDA yield and quality grades. Carcasses were fabricated according to National Association of Meat Purveyors (**NAMP**) specifications (NAMP, 1988), and the ribeye roll (NAMP 112) and chuck roll (NAMP 114) were removed from each carcass, vacuum-packaged, and transported to the University of Georgia Meat Science Laboratory. Upon arrival, pH was measured in three locations of the LM at the 12th rib using a spear-tip electrode (model 8163BN, Orion, Beverly, MA) connected to a portable pH meter with automatic temperature compensation (model 59002-30, Cole-Parmer, Vernon Hills, IL). The ribeye roll was further processed into steaks for fatty acid analysis, tenderness, sensory panel evaluation, and lipid and color stability measurements. Steaks designated for fatty acid analysis, shear force measurements, and sensory panel evaluation were individually vacuum packaged and frozen at –20°C for subsequent analysis. The clod was ground (0.635 cm) and prepared into 114-g patties. Steaks and patties for lipid and color stability measurements were individually placed on Styrofoam trays, wrapped with oxygen-permeable film, and displayed at 4°C in a cooler illuminated with 1,614-lx fluorescent lighting. Lipid oxidation and objective color measurements were taken on steaks and patties at 0, 5, 12, and 21 d, and 0, 2, 4, and 8 d of display, respectively.

Instrumental Color

Instrumental color measurements were recorded for L* (measures darkness to lightness; lower L* indicates a darker color), a* (measures redness; higher a* value indicates a redder color), and b* (measures yellowness; higher b* value indicates a more yellow color) using a Minolta chromameter (CR-310, Minolta Inc., Osaka, Japan) with a 50-mm-diameter measurement area using a D65 illuminant, which was calibrated using the ceramic disk provided by the manufacturer. Color readings were determined at 24 h postmortem on s.c. fat and the exposed LM after ribbing between the 12th and 13th ribs. Beef color measurements of LM steaks and ground beef were obtained at 0, 5, 12, and 21 d, and 0, 2, 4, and 8 d of display, respectively. Values were recorded from three locations of the upper surface of each steak and ground beef sample randomly selected to obtain a representative reading of the surface color.

Lipid Oxidation Analysis

Lipid stability was evaluated in the same steaks and ground beef that were displayed for instrumental color. Lipid oxidation was determined by measuring 2-thiobarbituric acid reactive substances (Jo and Ahn, 1998) at 0, 5, 12, and 21 d of display for steaks, and at 0, 2, 4, and 8 d of display for ground beef.

Fatty Acid Composition

Longissimus steaks, ground beef, and s.c. fat samples were submerged in liquid N (–196°C), pulverized, and stored anaerobically at –20°C. Total lipid was determined following the chloroform-methanol procedure of Folch et al. (1957), modified by using a 10:1 ratio of chloroform-methanol to sample. Extract containing approximately 25 mg of lipid was converted to fatty acid methyl esters following the method of Duckett et al. (2002). The fatty acid methyl esters were analyzed by GC (Agilent 6890; Aligent Technologies, Wilmington, DE), and separated using a 100-m capillary column (0.25-mm i.d. and 0.20-μm film thickness, SP 2560; Supelco, Bellefonte, PA). Column oven temperature was programmed at 150 to 165°C at 1°C/min, 165 to 167°C at 0.2°C/min, 167 to 225°C at 1.5°C/min, and held at 225°C for 15 min with 1:100 split. Injector

and detector temperatures were maintained at 250°C. Hydrogen was the carrier gas at a flow rate of 1 mL/min. Individual fatty acids were identified by comparison of retention times with standards (obtained from Sigma Chemical, St. Louis, MO; Supelco and Matreya, Pleasant Gap, PA).

Ergot Alkaloids in Fat

Ergot alkaloids were extracted from 5 g of homogenized fat by adding 1 mL of 0.1 *M* NaOH with 20 mL chloroform. The homogenate was vortexed for 5 min and filtered through a Whatman No. 41 filter paper. Five milliliters of 0.1 *M* hydrochloric acid was added to the chloroform with 15 mL of water, inverted to mix the solutions, and 15 mL of the aqueous layer were pipetted from the phase-separated sample. The pH of the decanted aqueous solutions was adjusted to 6.5 with 0.2 *M* NaOH, the samples frozen, and lyophilized. The lyophilized samples (salt plus alkaloids) were extracted with methanol, and taken to dryness in a vacuum chamber. Extracted samples were then analyzed for ergot alkaloids via a competitive ELISA as described by Adcock et al. (1997), using the ergot alkaloid-specific monoclonal antibody (15F3.E5).

Warner-Bratzler Shear Force

Steaks (2.5 cm thick) were vacuum-packaged, stored in a cooler at 4°C, and frozen after 2, 4, 8, 14, and 21 d of aging for subsequent Warner-Bratzler shear force determination. Steaks were thawed for 24 h at 4°C, and broiled on Farberware (Bronx, NY) electric grills to an internal temperature of 71°C (AMSA, 1995). Steaks were allowed to cool to room temperature before six 1.27-cm-diameter cores were removed from each steak parallel to the longitudinal orientation of the muscle fibers. All cores were sheared perpendicular to the long axis of the core using a TA-XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY) equipped with a Warner-Bratzler knife, and peak shear force was recorded. Crosshead speed was set at 20 cm/min.

Sensory Panel Evaluation

Steaks (2.5 cm thick) were vacuum-packaged, stored in a cooler at 4°C, and frozen at –20°C after 14 d of aging for subsequent trained sensory analyses. Steaks were thawed for 24 h at 4°C, and broiled on Farberware electric grills to an internal temperature of 71°C (AMSA, 1995). Steaks were immediately cut into 2.54 cm × 1.27 cm × 1.27 cm cubes, and served warm to a nine-member sensory panel trained according to AMSA (1995) guidelines. Each panelist evaluated two cubes from each sample for juiciness (amount of juice perceived in the mouth) and chewiness (amount of work it takes to get the samples ready to swallow) using a five-point scale (1 = not at all juicy or chewy, 5 = extremely juicy or chewy).

Statistical Analyses

Data were analyzed as a completely randomized design using the GLM procedure of SAS (SAS Inst., Inc., Cary, NC) with animal as the experimental unit. Lipid oxidation, objective color, and Warner-Bratzler shear force data were analyzed using repeated measures analysis, with endophyte type tested by the between-subjects error, and time and interaction between time and endophyte type tested by the within-subjects error term. Least squares means were generated and separated using the PDIFF option of SAS for main or interactive effects. Fatty acid data were analyzed as a 2×3 factorial with endophyte type (E+ and AR542), adipose tissue location (ground beef, LM, and s.c. fat), and two-way interaction in the model. There were no interactions between endophyte type and adipose tissue location for lipid content and fatty acid composition of the samples, with the exception of myristoleic acid. Thus, the fatty acid data are reported as main effects for endophyte type and adipose tissue location. Simple correlations between growth rate, fat depth, HCW, and LM color with Warner-Bratzler shear force values were computed using the correlation procedure of SAS. Significance was determined at $P \leq 0.05$, whereas differences of $P > 0.05$ to $P \leq 0.10$ were considered as trends.

Results and Discussion

Animal Performance and Carcass Traits

Effect of endophyte type on animal performance and carcass characteristics is presented in Table 1. Average daily gain was greater ($P < 0.05$) by 0.22, 0.49, and 0.37 kg/d for AR542 than E+ for fall, spring, and total grazing season, respectively. Live weight and HCW were greater ($P < 0.05$) for steers grazing AR542 than the steers grazing E+ infected tall fescue. Previous research has shown that tall fescue pastures infected with AR542 were promising alternatives for combating toxicosis and improving cattle growth rates and beef productivity (Parish et al., 2003; S. K. Duckett, unpublished data). Carcass traits, including quality and yield grades, did not differ ($P \geq 0.15$) between the endophyte types.

Instrumental Color, pH, and Lipid Oxidation

Effects of endophyte type on muscle pH, LM color, and s.c. fat color are shown in Table 2. Longissimus muscle pH at 24 h postmortem did not differ ($P = 0.87$) between treatments, and no differences ($P > 0.17$) in color (L*, a*, and b*) were observed for LM or s.c. fat between AR542 and E+ cattle. Longissimus muscle L* values reported here for pasture-finished beef were lower (darker) than those reported for concentrate-finished beef (Bidner et al., 1986; Bennett et al., 1995; McCaughey and Cliplef, 1996). Pasture-finished cattle typically have a more yellow fat color due to greater

Table 1. Least squares means (±SE) for steer performance and carcass characteristics as affected by endophyte type

	Endophyte type[a]		
Characteristic	E+	AR542	*P*-value
No. of steers	6	8	
ADG (fall 2000), kg/d	0.48 ± 0.054	0.69 ± 0.063	0.02
ADG (spring 2001), kg/d	0.12 ± 0.057	0.62 ± 0.049	0.01
Overall ADG, kg/d	0.28 ± 0.034	0.65 ± 0.029	0.01
Live weight, kg	411.93 ± 11.34	450.76 ± 9.82	0.02
HCW, kg	223.33 ± 7.92	246.36 ± 6.85	0.04
Dressing percent	54.13 ± 0.72	54.65 ± 0.63	0.60
Fat depth, cm	0.43 ± 0.054	0.53 ± 0.047	0.20
LM area, cm^2	51.75 ± 3.14	58.12 ± 2.72	0.15
Internal fat, %	0.92 ± 0.20	1.06 ± 0.17	0.59
Overall maturity[b]	143.33 ± 5.55	148.75 ± 4.81	0.48
Marbling score[c]	430.83 ± 10.51	411.25 ± 9.10	0.18
USDA quality grade[d]	3.00 ± 0.14	2.75 ± 0.12	0.21
USDA yield grade	2.41 ± 0.13	2.41 ± 0.12	0.99

[a]E+ = wild-type, and AR542 = novel, nil ergot alkaloid.
[b]100 to 199 = A-maturity, and 200 to 299 = B-maturity.
[c]400 to 499 = slight, and 500 to 599 = small.
[d]2 = High Standard, and 3 = Low Select.

concentration of β-carotene than carcasses from concentrate-fed cattle (Bennett et al., 1995; Simonne et al., 1996).

Steaks from E+ cattle tended to have higher (P = 0.10) L* and b* values than those from AR542 cattle on d 0 of simulated retail display (Table 3). There were no differences (P = 0.22) in steak redness (a*) associated with fescue endophyte type. Ground beef from E+ cattle was lighter (higher L* value; $P < 0.05$) than ground beef from AR542 cattle; however, a* and b* values did not differ ($P > 0.18$) between endophyte treatments. There were no differences ($P > 0.22$) in steak or ground beef color between the treatments measured at 5, 12, and 21 d, and 2, 4, and 8 d of display, respectively (results not shown). Lipid oxidation did not differ in ground beef (P = 0.36) or LM (P = 0.62) samples between endophyte treatments, and the interaction between endophyte type and time was non-significant (P = 0.16; results not shown). Lipid oxidation increased ($P < 0.01$) during simulated retail display.

Lipid Content and Fatty Acid Composition

The effect of endophyte type on lipid content and fatty acid composition pooled over adipose tissue location (ground beef, i.m., and s.c. fat) is presented in Table 4. No interactions ($P > 0.17$) were detected between endophyte type and adipose tissue location for lipid content and fatty acid composition, with the exception of myristoleic (C14:1) acid ($P < 0.05$). There were no differences between E+ and AR542 in the myristoleic acid content of ground beef and s.c. fat (0.42

Table 2. Least squares means (±SE) for longissimus muscle pH and color, and subcutaneous fat color as affected by endophyte type

	Endophyte type[a]		
Characteristic	E+	AR542	*P*-value
No. of steers	6	8	
LM pH at 24 h postmortem	5.70 ± 0.023	5.71 ± 0.020	0.87
LM muscle color[b]			
L*	35.75 ± 0.86	34.54 ± 0.75	0.31
a*	18.17 ± 0.73	17.62 ± 0.63	0.58
b*	6.01 ± 0.38	5.48 ± 0.33	0.31
Subcutaneous fat color[b]			
L*	79.00 ± 0.50	78.05 ± 0.43	0.17
a*	2.25 ± 0.33	2.68 ± 0.285	0.35
b*	11.74 ± 0.85	12.22 ± 0.74	0.68

[a]E+ = wild-type, and AR542 = novel, nil ergot alkaloid.
[b]L* = a measure of darkness (higher L* values indicate a lighter color); a* = a measure of redness (higher a* values indicates a redder color); and b* = a measure of yellowness (higher b* values indicates a more yellow color).

Table 3. Least squares means (±SE) for longissimus muscle steak and ground beef color on d 0 of simulated display as affected by endophyte type

	Endophyte type[a]		
Characteristic	E+	AR542	*P*-value
No. of steers	6	8	
Steaks[b]			
L*	38.25 ± 0.717	36.59 ± 0.621	0.10
a*	14.34 ± 0.968	13.08 ± 0.838	0.22
b*	5.08 ± 0.250	4.45 ± 0.217	0.10
Ground beef[b]			
L*	47.35 ± 0.748	45.01 ± 0.648	0.04
a*	21.98 ± 0.532	22.06 ± 0.461	0.90
b*	10.92 ± 0.424	10.12 ± 0.368	0.18

[a]E+ = wild-type, and AR542 = novel, nil ergot alkaloid.
[b]L* = a measure of darkness (higher L* values indicate a lighter color); a* = a measure of redness (higher a* values indicate a redder color); and b* = a measure of yellowness (higher b* values indicates a more yellow color).

vs. 0.44% and 0.30 vs. 0.38%, respectively), whereas C14:1 was higher ($P < 0.05$) in the i.m. fat from AR542 than E+ (0.87 vs. 0.47%, respectively).

Total lipid content was unaffected ($P = 0.45$) by endophyte type. Endophyte type did not alter ($P > 0.14$) the proportions of myristic (C14:0), palmitic (C16:0), linoleic (C18:2), linolenic (C18:3), arachidonic (C20:4), eicosapentaenoic (C20:5), docosapentaenoic (C22:5), or docosahexaenoic (C22:6) acids, unidentified fatty acids, or the percentage of total PUFA.

Adipose tissues from E+ cattle had higher ($P < 0.05$) proportions of stearic (C18:0) acid, and lower ($P < 0.05$) proportions of palmitoleic (C16:1) and oleic (C18:1) acids than AR542. Consequently, the percentage of SFA was higher ($P < 0.05$), and the percentage of MUFA was lower ($P < 0.05$) in the adipose tissues of E+ steers compared with AR542 steers.

Numerous disorders occur in livestock grazing infected tall fescue, and several clinical signs of toxicosis are consistent with the development of bovine fat necrosis. These include increased body temperature, decreased performance, and rough hair coat (Stuedemann et al., 1975; Hoveland et al., 1983; Stuedemann and Hoveland, 1988). Steers grazing E+ endophyte-infected tall fescue in this study exhibited these clinical signs of toxicosis. Stuedemann and Hoveland (1988) proposed that toxic tall fescue influences lipid metabolism, and that there may be a link between poor animal performance on tall fescue and occurrence of fat necrosis. Increased body temperature caused by heat stress or administration of a pyrogenic substance has been shown to alter lipid metabolism, resulting in

Table 4. Least squares means (±SE) for fatty acid composition (g/100 g of total fatty acids) pooled over three fat depots (ground beef, longissimus muscle, and subcutaneous fat) as affected by endophyte type

	Endophyte type[a]		
Item	E+	AR542	*P*-value
No. of samples	18	24	
Total fatty acids, g/100 g of fresh tissue	22.77 ± 0.95	23.73 ± 0.82	0.45
C14:0	2.66 ± 0.079	2.75 ± 0.068	0.41
C16:0	24.07 ± 0.24	23.60 ± 0.20	0.14
C16:1*cis*-9	2.10 ± 0.10	2.55 ± 0.085	0.01
C18:0	19.01 ± 0.55	17.22 ± 0.48	0.02
C18:1*cis*-9	33.06 ± 0.58	35.06 ± 0.50	0.01
C18:2*cis*-9,12	1.83 ± 0.082	1.69 ± 0.071	0.21
C18:3*cis*-9, 12, 15	0.81 ± 0.039	0.74 ± 0.034	0.20
C18:2*cis*-9, *trans*-11 CLA[b]	0.84 ± 0.060	0.98 ± 0.052	0.08
Total CLA[c]	1.04 ± 0.064	1.18 ± 0.055	0.10
C20:4*cis*-5, 8, 11, 14	0.40 ± 0.042	0.43 ± 0.036	0.55
C20:5*cis*-5, 8, 11, 14, 17 (EPA)	0.37 ± 0.043	0.34 ± 0.037	0.52
C22:5*cis*-7, 10, 13, 16, 19 (DPA)	0.41 ± 0.041	0.44 ± 0.035	0.62
C22:6*cis*-4, 7, 10, 13, 16, 19 (DHA)	0.04 ± 0.005	0.04 ± 0.005	0.85
Unidentified	13.81 ± 0.37	13.39 ± 0.32	0.40
SFA[d]	53.36 ± 0.75	50.64 ± 0.65	0.01
MUFA[d]	40.93 ± 0.73	43.74 ± 0.64	0.01
PUFA	5.71 ± 0.24	5.62 ± 0.21	0.79
PUFA:SFA ratio	0.11 ± 0.005	0.11 ± 0.005	0.72
n-6:n-3 ratio	1.40 ± 0.075	1.44 ± 0.065	0.72

[a]E+ = wild-type, and AR542 = novel, nil ergot alkaloid.
[b]CLA = conjugated linoleic acid, *cis*-9, *trans*-11 isomer.
[c]Total CLA = sum of all CLA isomers (*cis*-9, *cis*-11; *trans*-9, *trans*-11); *trans*-10, *cis*-12 isomer was not detected in any samples.
[d]SFA = C14:0, C16:0, C18:0, and MUFA = C14:1, C16:1, C18:1. Total SFA, MUFA, and PUFA values were calculated and corrected for the unidentified fatty acids, so that the three values add to 100%.

Table 5. Least squares means for fatty acid composition (g/100 g of total fatty acids) of ground beef, longissimus muscle (i.m.) fat, and subcutaneous fat (SQ) pooled across endophyte types

Item	Ground beef	LM	SQ	SEM	*P*-value
No. of samples	14	14	14		
Total fatty acids, g/100 g of fresh tissue	11.59[e]	1.46[f]	56.70[d]	1.087	0.01
C14:0	2.90[d]	3.14[d]	2.07[e]	0.090	0.01
C16:0	23.90[d]	24.65[d]	22.96[e]	0.269	0.01
C16:1*cis*-9	2.33[de]	2.64[d]	2.02[e]	0.112	0.01
C18:0	19.54[d]	18.55[d]	16.26[e]	0.632	0.01
C18:1*cis*-9	35.30[d]	34.90[d]	31.97[e]	0.666	0.01
C18:2*cis*-9,12	1.78[e]	0.77[f]	2.75[d]	0.093	0.01
C18:3*cis*-9, 12, 15	0.63[e]	0.49[f]	1.21[d]	0.044	0.01
C18:2*cis*-9, *trans*-11 CLA[a]	0.97[d]	1.04[d]	0.71[e]	0.068	0.01
Total CLA[b]	1.24[d]	1.24[d]	0.85[e]	0.073	0.01
C20:4*cis*-5, 8, 11, 14	0.08[d]	0.03[d]	1.14[e]	0.048	0.01
C20:5*cis*-5, 8, 11, 14, 17 (EPA)	0.35[e]	0.03[f]	0.68[d]	0.049	0.01
C22:5*cis*-7, 10, 13, 16, 19 (DPA)	0.25[e]	0.08[f]	0.94[d]	0.046	0.01
C22:6*cis*-4, 7, 10, 13, 16, 19 (DHA)	0.03[e]	0.01[f]	0.09[d]	0.006	0.01
Unidentified	11.25[f]	12.83[e]	16.73[d]	0.420	
SFA[c]	53.21[d]	53.18[d]	49.62[e]	0.856	0.01
MUFA[c]	41.99[de]	43.81[d]	41.21[e]	0.840	0.09
PUFA	4.81[e]	3.02[f]	9.18[d]	0.280	0.01
PUFA:SFA ratio	0.09[e]	0.06[f]	0.19[d]	0.006	0.01
n-6:n-3 ratio	1.55	1.35	1.36	0.086	0.18

[a]CLA = conjugated linoleic acid, *cis*-9 *trans*-11 isomer.
[b]Total CLA = sum of all CLA isomers (*cis*-9 *cis*-11, and *trans*-9 *trans*-11); *trans*-10 *cis*-12 isomer was not detected in any samples.
[c]SFA = C14:0, C16:0, and C18:0, and MUFA = C14:1, C16:1, and C18:1. Total SFA, MUFA and PUFA values were calculated and corrected for the unidentified fatty acids so that the three values add to 100%.
[d,e,f]Within a row, least squares means that do not have a common superscript letter differ, $P < 0.05$.

lower blood cholesterol concentrations (Noble et al., 1973; O'Kelly and Reich, 1975). Stuedemann et al. (1985) reported that necrotic fat contains more CP and ash, with less ether-extractable material, and three to four times higher cholesterol content than normal fat. Rumsey et al. (1979) studied the chemical composition of necrotic fat lesions in beef cows grazing fertilized "Kentucky-31" tall fescue, and reported that the molar proportion of stearic acid was greater, whereas the proportions of oleic and palmitoleic acids were lower, in the necrotic fat residue than in normal fat residue. Steers slaughtered in this study did not show any occurrence of nercrotic fat tissue in the perirenal region. Necrotic fat lesions have typically only been reported in aged cows with extended exposure to E+ tall fescue. Although we did not observe the appearance of necrotic fat lesions, results from the fatty acid composition analysis (higher C18:0 and lower C14:1, C16:1, and C18:1 in E+ fat) suggest that fescue toxicosis may influence lipid metabolism and contribute to the occurrence of fat necrosis. The greater concentration of stearic acid combined with the lower percentage of MUFA, particularly oleic acid, in adipose tissues from E+ cattle suggests that fescue toxicosis may inhibit Δ-9 desaturase, which is responsible for the conversion of stearic acid to oleic acid in adipose tissues.

Adipose tissue from AR542 cattle tended ($P = 0.08$) to have a higher proportion of CLA isomer *cis*-9, *trans*-11 and total CLA than E+. The n-6:n-3 ratio did not differ ($P > 0.72$) between E+ and AR542 cattle, and these levels are considered beneficial from a human health perspective compared to higher ratios reported in the literature for feedlot cattle (4.15, French et al., 2000; 6.38, Rule et al., 2002).

Total lipid content and fatty acid composition of ground beef, LM, and s.c. fat from the rib pooled over endophyte type (E+ vs. AR542) are shown in Table 5. As expected, total fatty acid content of the three tissues differed ($P < 0.01$) greatly, with s.c. fat containing the highest amount (56.7%) and LM containing the lowest (1.46%). Fatty acid profile shows that the lipid composition of i.m. fat more closely resembled that of ground beef than s.c. fat. The proportions of myristic, palmitic, stearic, and oleic acids did not differ between ground beef and LM, but were higher ($P < 0.05$) for these tissues than in s.c. fat. Consequently, the percentage of total SFA was lower ($P < 0.05$) in s.c. fat compared with either ground beef or LM. The concentrations of palmitoleic acid and total MUFA were lower ($P < 0.05$) in s.c. than LM and ground beef, which did not differ.

The proportions of the PUFA, including linoleic, linolenic, eicosapentaenoic, docosapentaenoic, and docosahexaenoic acids, were highest ($P < 0.05$) in s.c. fat and lowest ($P < 0.05$) in ground beef. Arachidonic acid concentrations were higher ($P < 0.05$) in s.c. than LM and ground beef fat. As a result, the proportion of total PUFA and the PUFA:SFA ratio were higher ($P < 0.05$) for s.c. fat than the LM, with ground beef fat being

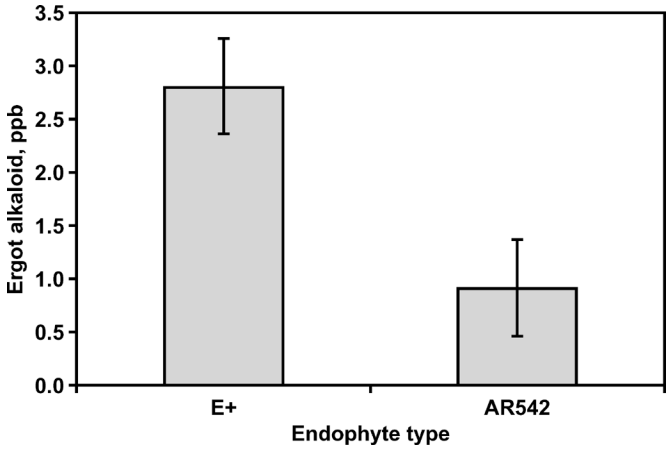

Figure 1. Effect of endophyte type (E+ = wild type endophyte-infected tall fescue, or AR542 = novel, nil ergot alkaloid endophyte-infected tall fescue) on the content of ergot-alkaloids in subcutaneous fat (P = 0.01) from E+ and AR542 cattle (fresh-tissue basis).

intermediate. In contrast, LM typically contains higher levels of PUFA than s.c. fat in beef from concentrate-finished cattle (Gillis et al., 2004). Mitchell et al. (1991) indicated that lipid content and fatty acid composition varied with tissue site reporting higher concentrations of PUFA and lower concentrations of MUFA in i.m. fat compared to s.c. fat. These differences in PUFA between forage-finished and concentrate-finished beef are likely the result of greater dietary linolenic acid intake throughout the finishing period and lower rates of fat accretion for forage-finished compared with concentrate-finished cattle.

Differences between adipose tissues were not (P = 0.18) observed for the n-6:n-3 fatty acid ratio. Concentrations of total CLA and CLA isomer *cis*-9, *trans*-11 were lower ($P < 0.05$) in subcutaneous fat compared to either LM or ground beef. French et al. (2000) reported similar CLA concentrations in LM for grass-fed beef (10.8 mg of CLA/g of lipid). Previous research has shown that including grass in the diet of dairy and beef cattle increased CLA concentration in milk and intramuscular fat, respectively (Lawless et al., 1998; French et al., 2000; Yang et al., 2002). Shantha et al. (1997) reported 7.7 and 5.2 mg total CLA/g lipid in semimembranosus muscle for grass-fed and corn supplemented, grass-fed beef, respectively. Rule et al. (2002) reported 4.1 and 2.6 mg CLA *cis*-9, *trans*-11/g lipid in LM for pasture-fed cows and feedlot steers, respectively. The CLA concentrations reported in this study were higher than values reported for LM from feedlot cattle (*cis*-9, *trans*-11 = 0.599%, and total CLA = 0.919%; Gillis et al., 2004). French et al. (2000) reported 3.7 mg total CLA/g lipid for beef cattle fed concentrates, whereas Mir et al. (2000) reported 1.7 mg of total CLA/g of lipid for cattle fed a barley-based diet.

The CLA concentrations reported for ground beef in this study were higher than previously published values. Chin et al. (1992) reported CLA concentrations in ground beef of 4.3 mg/g of lipid, whereas Shantha et al. (1994) reported a range in CLA concentrations for ground beef from the chuck between 6.6 and 8.2 mg/g of fat. Both Chin et al. (1992) and Shantha et al. (1994) obtained samples from retail market; thus, the different nutritional background of the steers in this study would likely explain the higher levels observed.

Ergot Alkaloids

Subcutaneous fat from E+ cattle had higher ($P <$ 0.01) concentrations of ergot alkaloids than AR542 (Figure 1). These results show that ergot alkaloids ingested during grazing were deposited in adipose tissue. Presence of ergot alkaloids detected in s.c. fat from AR542 cattle may be a result of exposure of steers to endophyte-infected tall fescue with toxic endophyte before this experiment. This is, to the authors' knowledge, the first published report showing that ergot alkaloids accumulate in adipose tissues when cattle graze tall fescue pastures infected with toxic endophyte.

Previous research has shown that approximately 94% of the ergot alkaloids are excreted in the urine of cattle grazing endophyte-infected tall fescue and that urinary alkaloids are rapidly metabolized and voided from urine when steers are removed from pastures (Stuedemann et al., 1998; Hill et al., 2000). Rapid excretion and clearance of ergot alkaloids in urine suggests that cattle finished on concentrates after grazing endophyte-infected tall fescue would not exhibit carryover effects from fescue toxicosis during the finishing phase. However, toxicosis symptoms have been reported for feedlot cattle that previously grazed endophyte-infected tall fescue compared to endophyte free or nonergot alkaloid-producing endophyte-infected pastures (S. K. Duckett, unpublished data). Ergot alkaloids present in fat tissues from cattle previously grazing endophyte-infected tall fescue may be metabolized during the feedlot phase, causing residual toxicosis symptoms and poor cattle performance.

Warner-Bratzler Shear Force and Sensory Analysis

Shear force values did not differ (P = 0.16) between endophyte types (Figure 2A), but decreased (P = 0.01) across the postmortem aging curve (Figure 2B). Initial shear force values (9 kg) reported here would be classified as "tough" and would be predicted to not reach threshold levels (4.6 kg) for acceptable tenderness according to Shackelford et al. (1997). Shear force values decreased 2.5 and 4.3 kg from initial values to d 4 and d 14 postmortem, respectively. At 14 d of aging, shear force values decreased to 4.6 kg, a level that would be on the upper limit of threshold WBSF values considered acceptable for tenderness by consumers (3.0 to 4.6

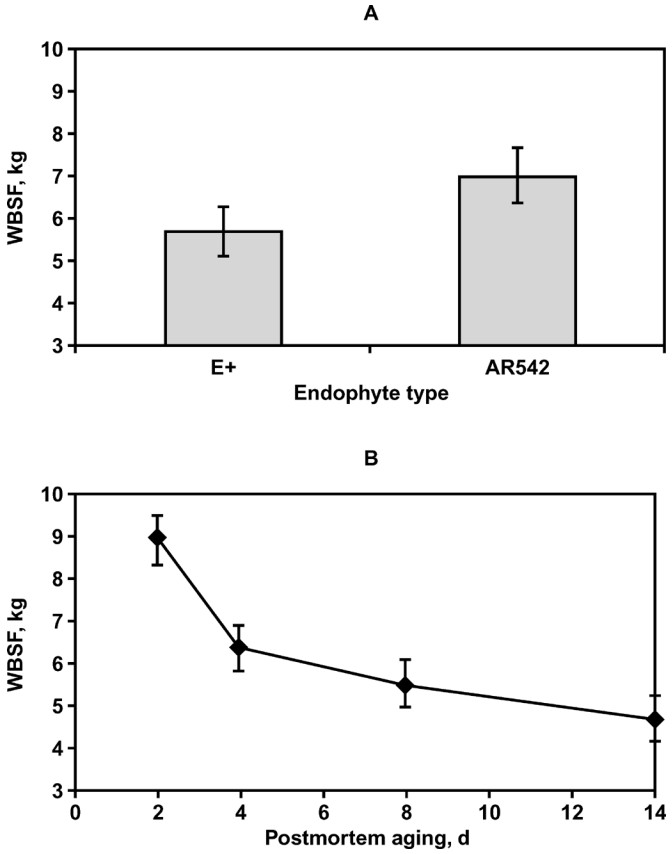

Figure 2. Effect of: A) endophyte type (E+ = wild type endophyte-infected tall fescue, or AR542 = novel, nil ergot alkaloid endophyte-infected tall fescue; $P = 0.16$); and B) postmortem aging ($P = 0.01$) on Warner-Bratzler shear force (WBSF) values.

kg at d 14 for 93% consumer tenderness acceptability, Miller et al., 2001; <4.6 kg at d 14, Shackelford et al., 1997). Changes in shear force reported here for pasture-finished beef suggest that the postmortem aging response reported for pasture-finished beef may differ from those typically reported for concentrate-finished beef. Previous research comparing tenderness of pasture- and concentrate-finished beef has produced mixed results on palatability attributes. Some studies found a negative effect of forage-finishing on meat tenderness (Smith, 1990; Mitchell et al., 1991), whereas others showed that grass-fed beef can be produced with no deleterious effects on meat quality, including tenderness (Mandell et al., 1998; French et al., 2001). In many experiments, dietary effects were confounded with other factors known to influence tenderness (animal age, growth rate, carcass weight, and external fat cover), and multiple postmortem aging times have not been evaluated. Additional research is needed to assess differences in postmortem myofibrillar degradation and calpain proteolytic system during postmortem aging between pasture- and concentrate-finished beef.

Steaks from AR542 steers were rated higher ($P = 0.01$) in chewiness and were less ($P = 0.08$) juicy than steaks from E+ steers aged for 14 d (Table 6). Cattle that grow more rapidly before slaughter have increased rates of protein turnover, resulting in higher concentrations of proteolytic enzymes in carcass tissues at slaughter which, in turn, may affect collagen solubility and/or myofibril fragmentation (Aberle et al., 1981; Hall and Hunt, 1982; Miller et al., 1983). Numerous studies (Bowling et al., 1978; Lochner et al., 1980; Dolezal et al., 1982) have reported a positive correlation between muscle tenderness, carcass weight, and fatness in feedlot cattle. However, other research has shown no relationship between carcass weight or carcass fat score and WBSF (French et al., 2001). In the present study, there were no significant correlations between ADG, fat depth or WBSF, whereas HCW was positively correlated with WBSF ($r = 0.68$; $P < 0.05$) measured at 2 d postmortem.

Table 6. Least squares means (±SE) for sensory panel ratings of longissimus muscle steaks as affected by endophyte type

	Endophyte type[a]		
Item	E+	AR542	*P*-value
No. of steers	6	8	
Chewiness[b]	2.80 ± 0.134	3.65 ± 0.114	0.01
Juiciness[b]	2.65 ± 0.097	2.43 ± 0.083	0.08

[a]E+ = wild-type, and AR542 = novel, nil ergot alkaloid.
[b]1 = not at all chewy or juicy; 5 = extremely chewy or juicy.

Implications

Nil ergot alkaloid endophyte-infected tall fescue is a promising alternative method to combat fescue toxicosis, and it greatly improves steer growth rate, as well as finishing and carcass weights. Nonetheless, results from this study suggest that endophyte type has minor effects on carcass traits and meat quality of grass-fed beef. Fescue toxicosis seems to influence fatty acid metabolism and may be involved in fat necrosis. This is the first published report showing that ergot alkaloids ingested during grazing are deposited in adipose tissue, which may explain residual toxicosis symptoms observed in feedlot cattle. Finishing cattle on tall fescue pastures may enhance the fatty acid profile of beef, including conjugated linoleic acid and n-3 fatty acids.

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